Calorimetry techniques for absolute dosimetry of laser-driven ion beams

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BLIN4: Beam Line and INstrumentation: Fourth Workshop

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Presentation Outline

- Ultrahigh pulse dose rate (UHPDR) beams
- Potential for new systems based on laser-driven approaches
- Challenges for dosimetry of UHPDR beams
- Resolution through calorimetry techniques for absolute dose measurements
- Outlook, acknowledgements, references

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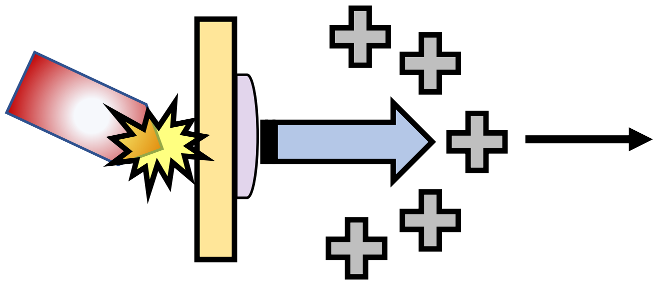
Ultra-High Pulse Dose Rate Beams

Maximum deliverable radiation dose limited by normal tissue toxicities

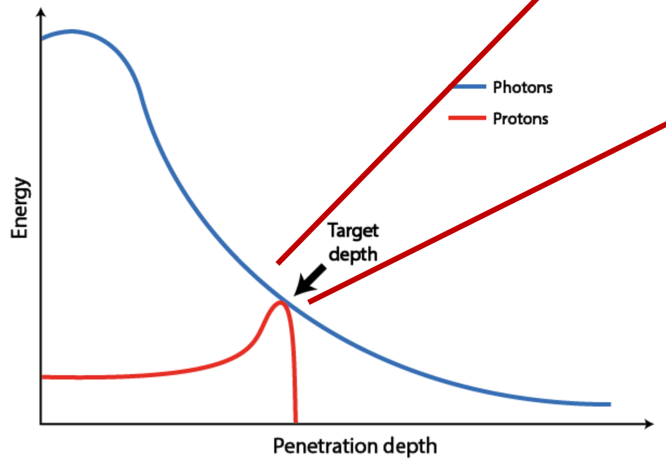
Studies using ultra-high pulse dose rates (UHPDR) decreased undesired effects

- *In vivo* studies of so-called **FLASH effect**
- Even higher dose-rate per pulses produced by **laser-matter interaction**

Ultrashort durations (~ 10 fs)
High dose rate per pulse (10^9 Gy/min)
Up to 100% energy distribution



Protons produced through laser-target interaction (TNSA mechanism)



A. Sebald, (2019)

Necessary to characterize these polyenergetic beams through accurate spectra measurements – **vital for clinical applications requiring precise energy selection**

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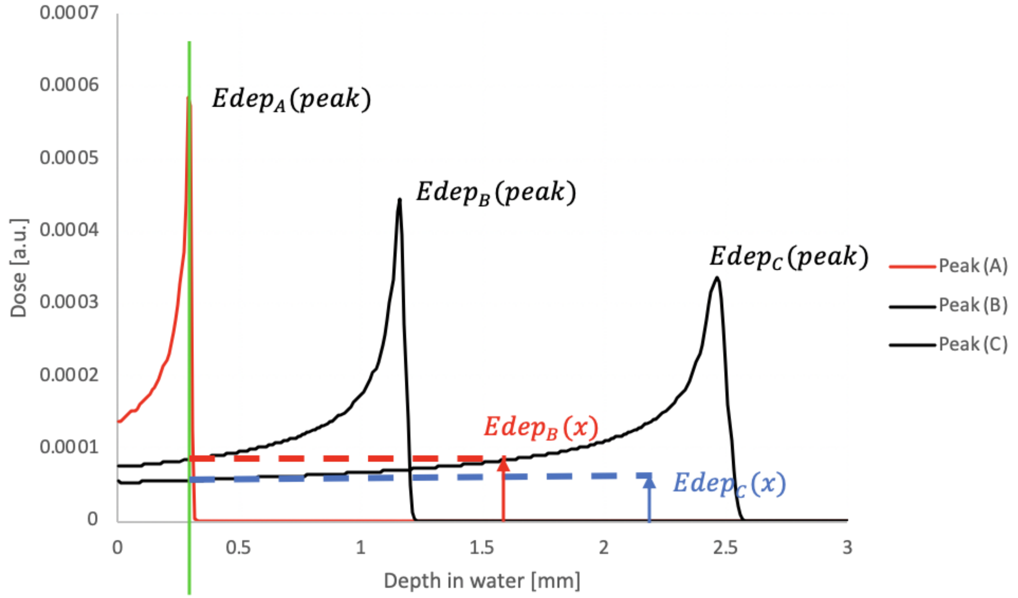
Characterizing Energy Spectra of Laser-Driven Beams

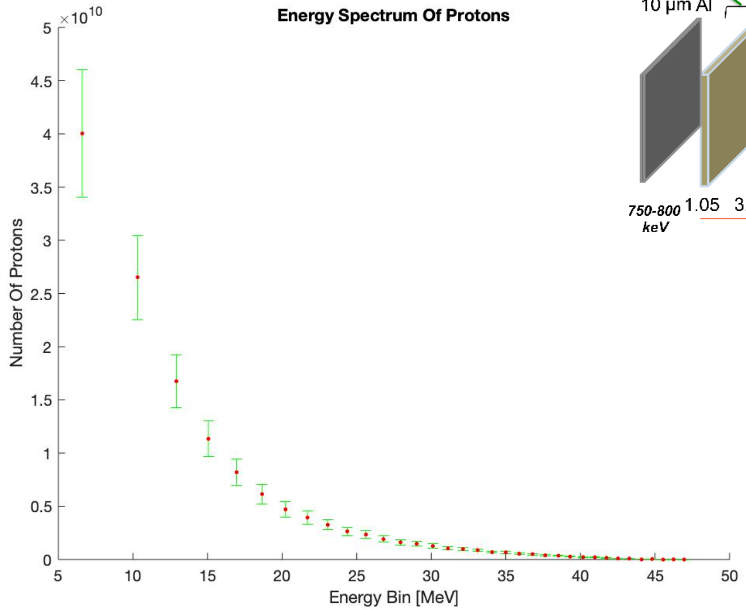
RCF stack configurations lend themselves well to measurements of these types

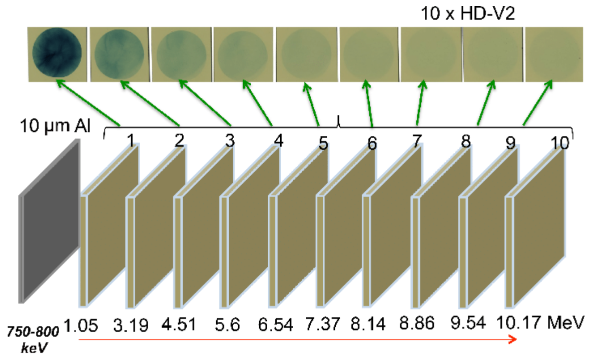
- Dose rate **independent**

Energy spectrum of polyenergetic proton beams obtained through **deconvolution**

- Low energy protons stopped in **first layers**
- Energetic protons deposit **fraction of their energy in every RCF** they pass
- **Weighted subtraction** of high energy dose contributions







L. Volpe, et al., (2019)

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Dosimetry Challenges at Ultra-High Dose Rates

Accurate dosimetry of high dose-rate particle beams is challenging

- Response of established active detectors **influenced by high dose rates**
- Generation of large electromagnetic pulse during laser-target interaction

The big picture with radiation dosimetry – **understanding the biological response**

Conventional source:
Controlled delivery

Laser-driven approach:
Particle burst

Revision of current dosimetry protocols and framework for dose measurements required

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UHDpulse EMPIR Project

EMPIR EURAMET

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Aim of developing a measurement framework

- Validating methods for radiation dose measurements
- Reference standards traceable to SI units
- Characterise response of detectors with UHPDR beams

UHDpulse: *Metrology for advanced radiotherapy using particle beams with ultra-high pulse dose rates*

Composed of large consortium of leading research institutes;

- *5 National Metrology Institutes (NMI's)*
- *2 academic hospitals*
- *3 universities*
- *3 national research institutes*
- *1 European research institute*
- *2 companies*

NMI's	Irradiation facilities	Detector developer
PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin	CHUV Centre hospitalier universitaire vaudois	ADVACAM Imaging the Unseen
NPL National Physical Laboratory	institut Curie	CSIC cnm
METAS	eli beamlines	USC Universidade de Santiago de Compostela
CMI Czech Metrology Institute	Nuclear Physics Institute of the CAS public research institution	POLITECNICO MILANO 1863
Central Office of Measures	Queen's University Belfast	PTW The Dosimetry Company
	HZDR Helmholtz Zentrum Dresden Rossendorf	

UHDpulse

Queen's University Belfast

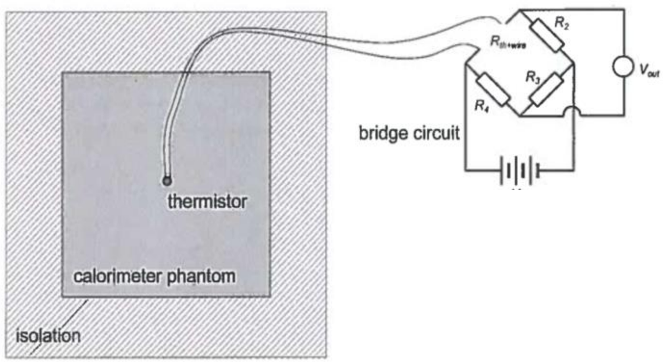
Dosimetry through Calorimetry Techniques

Innovative approach developed by National Physical Laboratory (NPL)

- Dosimetry of laser-driven beams through **calorimeters** thus far **unexploited**

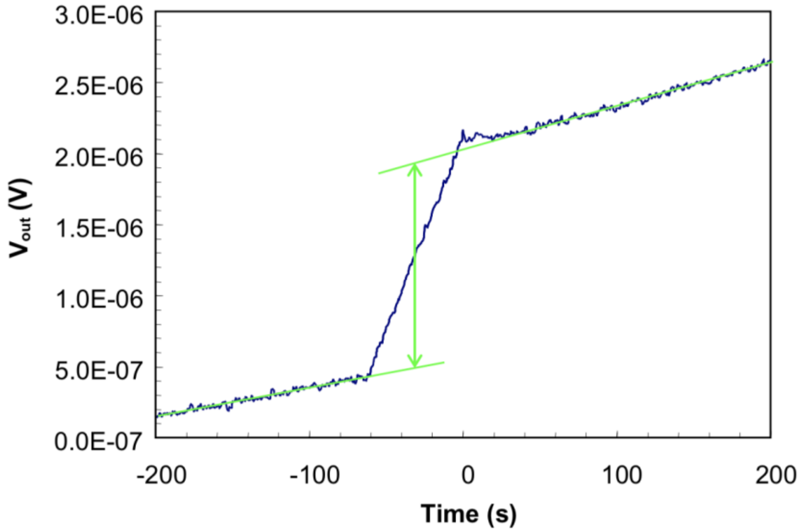
Calorimetry measures radiation induced temperature rise

- Rise in T converted to absorbed dose; $D_W = c_x \Delta T f_{w,x}$
- **Absolute dosimeter** – calibrated radiation field not required



Use of water and graphite calorimeters have been demonstrated with proton beams
Graphite preferred at **NPL** due to **higher sensitivity**

R. Thomas, (2016)



Primary standard for absorbed dose measurements in clinical proton beams based on graphite calorimeter at NPL

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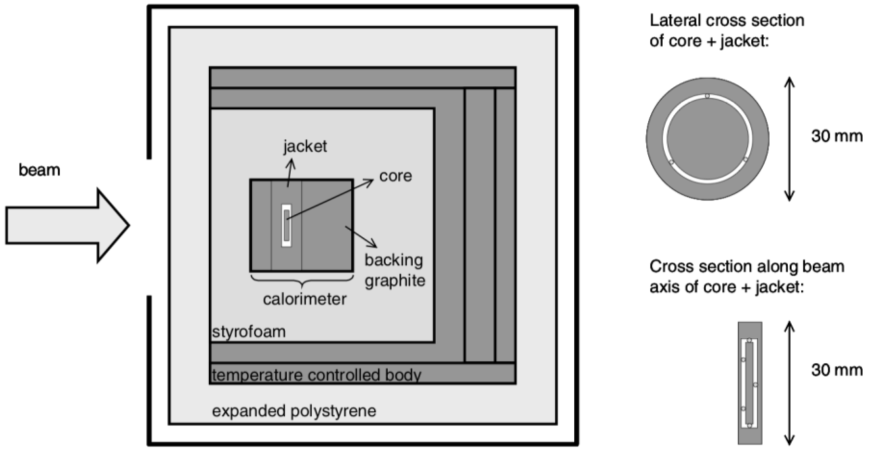
Development of the Small Portable Graphite Calorimeter

Small portable graphite calorimeter (SPGC) completely refurbished at NPL

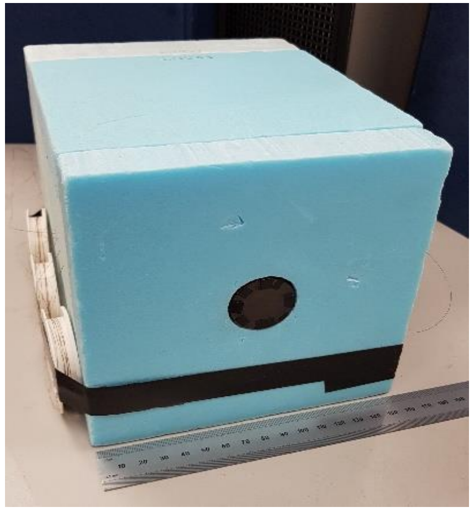
- Original use in measurement of low energy proton beams

Cylindrical arrangement of graphite components

- Core enclosed within graphite jacket, plus additional graphite slabs
- Styrofoam added to provide thermal isolation



H. Palmans, et al., (2004)



SPGC Features

SPGC core contains four thermistors

- Capable of detecting **mK** temperature changes

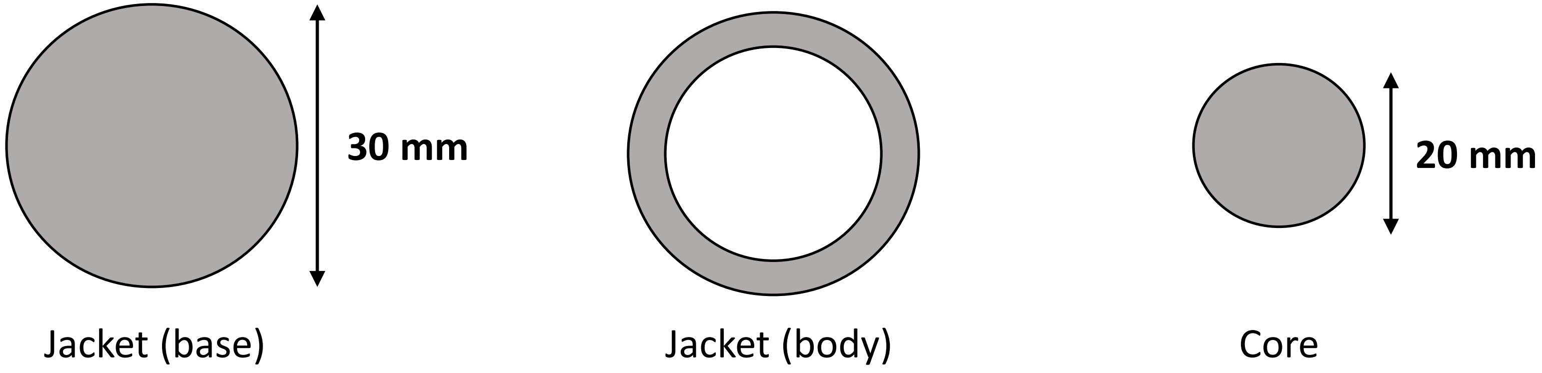
Two jacket thermistors added allowing jacket temperature measurements

- Assessments of jacket-core heat transfer
- Possibility to operate in **constant temperature** mode

One additional thermistor added to monitor the ambient temperature

Functional tests successfully performed at NPL using conventional photon beams

Small temperature increases involved **(~ 1.4 mK for a dose of 1 Gy**)
→ sensitive measuring equipment and excellent temperature control required



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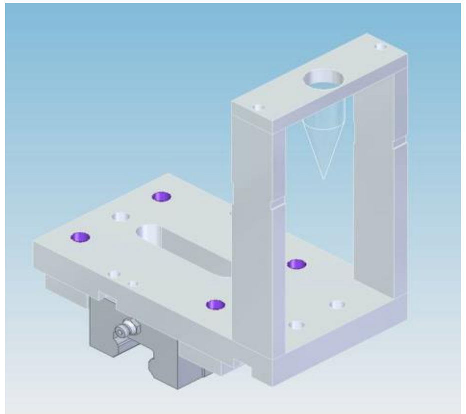
Calorimetry for Laser-Driven Beams

First **ever** recorded absorbed dose measurement using calorimetry

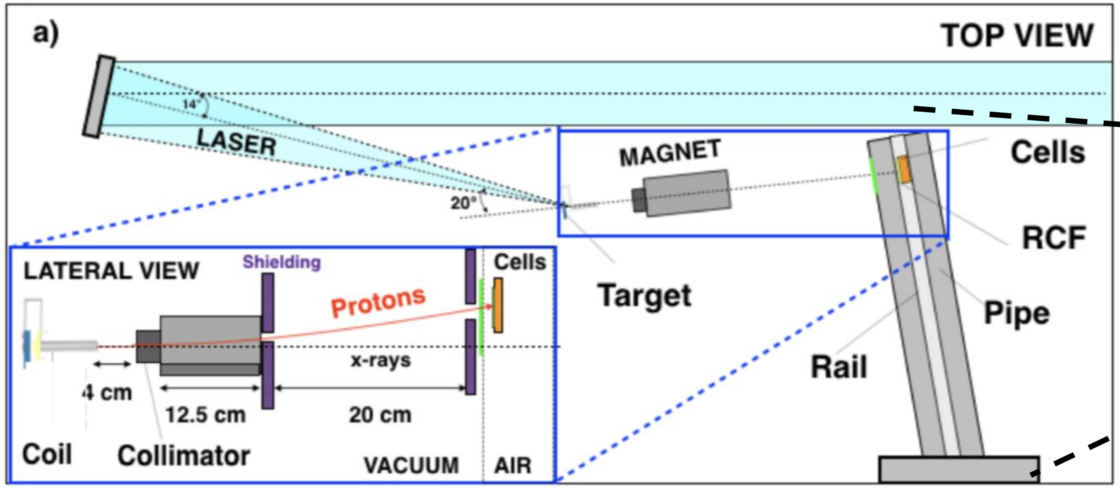


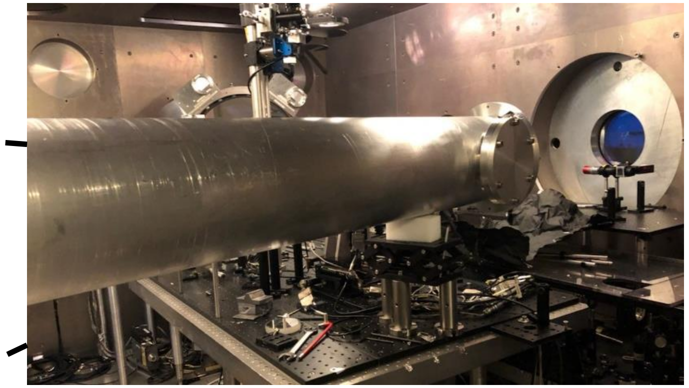
Measurements conducted using VULCAN PW laser of CLF

- Using setup for radiobiology experiment of 3D tumor cell irradiation
- Holder designed to be placed in re-entrance pipe

Monte Carlo simulations performed prior (working in TOPAS/Geant4 codes)

- Simulation of SPGC for dose prediction using laser-driven proton parameters





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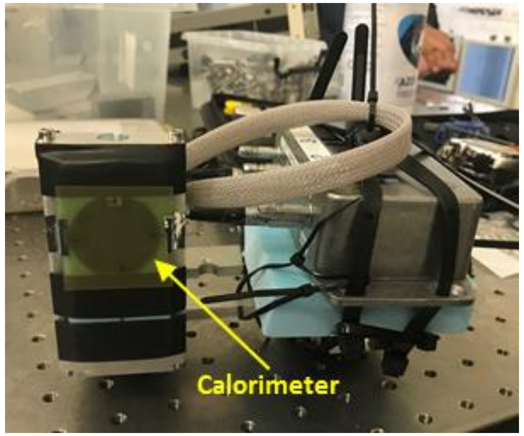
Proof of Principle Measurement – July 2019

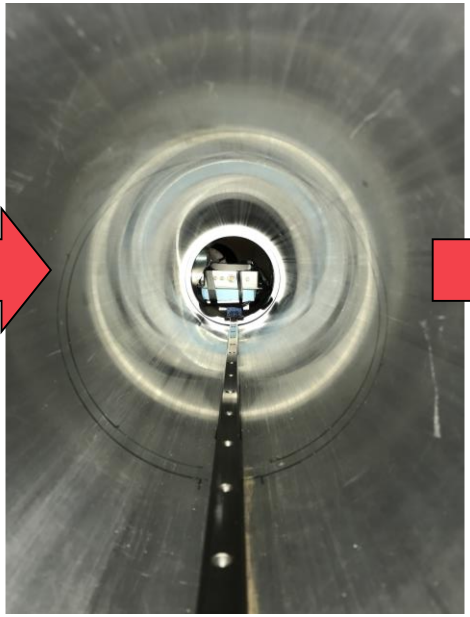
First test of calorimetry techniques using laser system

Requirement: laser-driven protons of ≥15 MeV needed

- In order to penetrate graphite jacket and reach core
- Thin walled to minimize beam divergence/absorption

- **VULCAN PW** pulses of **600 J** and **~500 fs**
- Focused Intensities > **10^{20} W/cm^2**
- Protons between **20 – 45 MeV** produced
- Energy separation using **0.9 T** dipole magnet
- Doses from **1-3 Gy per pulse**





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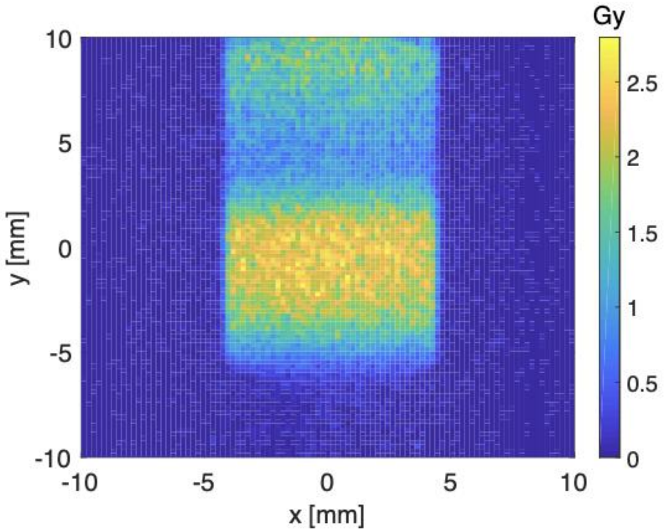
Proof of Principle Measurement – July 2019

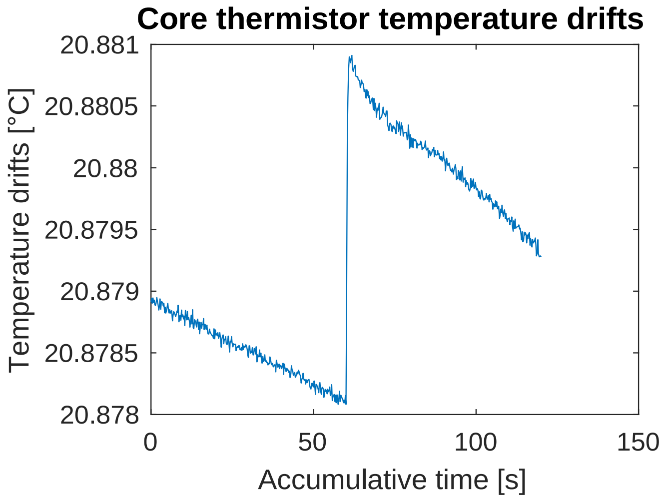
Total of **five** shots performed with this setup

- Four at full power (~600 J) directly onto calorimeter
- One with calorimeter taken from re-entrance pipe (assess EMP)

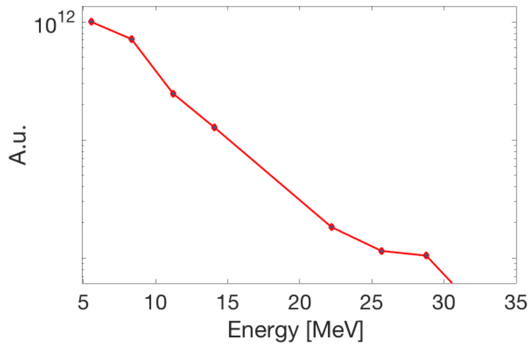
Analyzing the temperature drifts for each shot, and converting to absorbed dose:
1) 2.2 Gy, 2) **1.2 Gy**, 3) **1.7 Gy**, 4) **0.413 Gy**



Expected dose map obtained from Monte Carlo simulations



Radiation induced temperature rises of one of the core thermistors for first laser shot



Simulated energy spectrum

Discrete component positioning provided protects circuitry

- Feasibility of calorimetry in laser demonstrated

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Summary and Outlook

- UHPDR/laser-driven beams offer potential benefits for applications
- Challenges associated with dosimetry at these high dose rates
- Alternative approach through calorimetry of laser-driven beams demonstrated
- Dedicated campaign for calorimetry measurements of laser-driven protons proposed
- Results will serve as a tool to aid potential clinical applications of these beams

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Thank you for your attention!

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